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Dark Matter at the Galactic Center

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Particle dark matter near the galactic center is accreted by the central black hole into a dense spike, strongly enhancing its annihilation rate. Searching for its annihilation products may give us information on the presence or absence of a central cusp in the dark halo profile.

This is a summary of a paper of ours, ref. [1], in which we use the absence of neutrino signals from the galactic center to bound the steepness of a possible central cusp in a dark matter halo made of neutralinos. This summary updates the bounds published in [1] by using the current upper limit by the MACRO collaboration [2] on the neutrino emission from the galactic center.[1]

The evidence is mounting for a massive black hole at the galactic center. Ghez et al. [3] have confirmed and sharpened the Keplerian behavior of the star velocity dispersion in the inner 0.1 pc of the galaxy found by Eckart and Genzel [4]. These groups estimate the mass of the black hole to be $M = 2.6 \pm 0.2 \times 10^6 \, M_\odot$.

If cold dark matter is present at the galactic center, as in current models of the dark halo, it is accreted by the central black hole into a dense spike. Particle dark matter then annihilates strongly inside the spike, making it a compact source of photons, electrons, positrons, protons, antiprotons, and neutrinos.

The spike luminosity depends on the density profile of the inner halo: halos with finite cores have unnoticeable spikes, while halos with inner cusps may have spikes so bright that the absence of a detected neutrino signal from the galactic center already places interesting upper limits on the density slope of the inner halo.

[1]Thanks to Francesco Ronga for communicating the new upper limit.

Figure 1 illustrates the two classes of halo models. The "empirical" models are fit to the data and have a central region of constant density, called the core. The "theoretical" models arise from the results of numerical N-body simulations and have a power law density profile in the inner region, dubbed the cusp. Actually, even the highest resolution results presently available extend inwards only to ~ 1 kpc, but we have boldly extrapolated the cusp to the inner parsec.

The effect of the central black hole on the dark matter distribution in its neighborhood can be found in the following way. Before the formation of the black hole, the dark matter density within its radius of influence (~ 0.2 pc) can be assumed to be either constant or a power law of index γ ($\rho \sim r^{-\gamma}$). The dark matter density after the formation of the black hole is obtained by assuming that the black hole grows slowly and hence the dark matter distribution evolves adiabatically. Conservation of the three adiabatic invariants – phase-space density, angular momentum, and radial action – then gives the final dark matter density.

A power-law density profile results around the black hole, with an index $\gamma_{\rm spike}$ that depends on the initial index γ and on the analytical properties of the initial profile, i.e. core or cusp. We call "spike" this density enhancement close to the black hole, to distinguish it from the cusp further out. The maximum density in the spike is reached

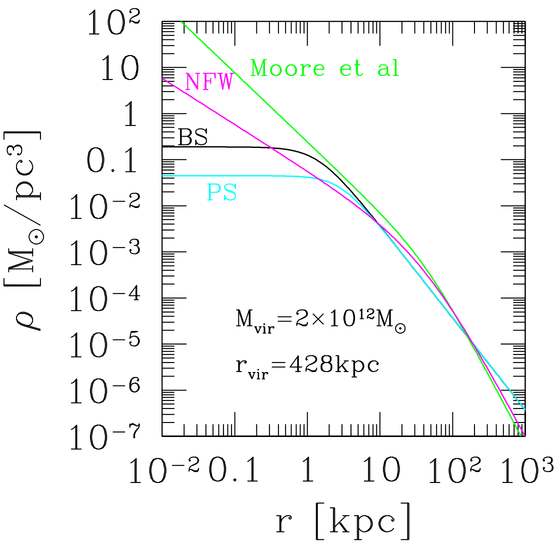

Figure 1. Two classes of dark matter profiles for our galactic halo: with a central core (BS [5] and PS [6]) and with a central cusp (NFW [7] and Moore et al. [8]).

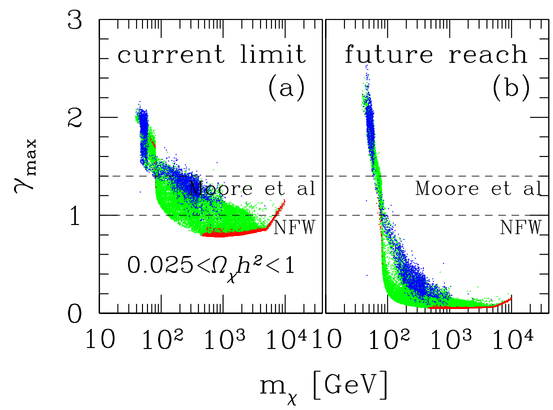

Figure 2. Maximum inner slope γ of the dark matter halo compatible with the upper limit on the neutrino emission from the galactic center. (a) Current limit at 1 GeV; (b) future reach at 25 GeV.

either at the small distance of ~ 10 Schwarzschild radii within which dark matter is captured by the black hole, or at a larger radius where the annihilation time becomes equal to the age of the black hole and within which the density is constant. Examples of spike density profiles are given in [1].

Annihilation signals, which increase with the square of the density, are enhanced dramatically. The enhancement increases with increasing initial slope γ, and this allows an upper limit to be set on the value of γ given an upper limit on some of the annihilation signals from the galactic center. In [1] we considered the neutrino emission. High energy neutrinos from the galactic center could be detected with a neutrino telescope in the Northern hemisphere through their conversion to muons in a charge current interaction in the rock surrounding the detector.

The current bound [2] on the neutrino emission from the galactic center is 1104 neutrino-induced muons > 1 GeV per km^2 per year. We impose this bound on the emission expected from neutralino dark matter in the minimal supersymmetric model, calculated using the DarkSUSY code [9]. We use the database of points in supersymmetric parameter space built in refs. [10–12], namely the 35121 points in which the neutralino is a good cold dark matter candidate, in the sense that its relic density satisfies $0.025 < \Omega_\chi h^2 < 1$. The upper limit comes from the age of the Universe, the lower one from requiring that neutralinos are a major fraction of galactic dark halos.

For each point in parameter space, we can then obtain a separate upper bound $\gamma_{\max}$ on the inner halo slope. These bounds are plotted in figure 2a. (Plotted values of $\gamma_{\max} > 2$ are unphysical extrapolations but are shown for completeness.) Present bounds are of the order of $\gamma_{\max} \sim 0.5$, right in the ballpark of current results from N-body calculations.

Future neutrino telescopes observing the galactic center could probe the inner structure of the dark halo, or indirectly find the nature of dark matter. For example, with a muon energy threshold of 25 GeV, the neutrino flux from the spike after imposing the current constraints could still be over 2 orders of magnitude above the atmospheric background (Fig. 3), allowing to probe γ as low as 0.05 (Fig. 2b).

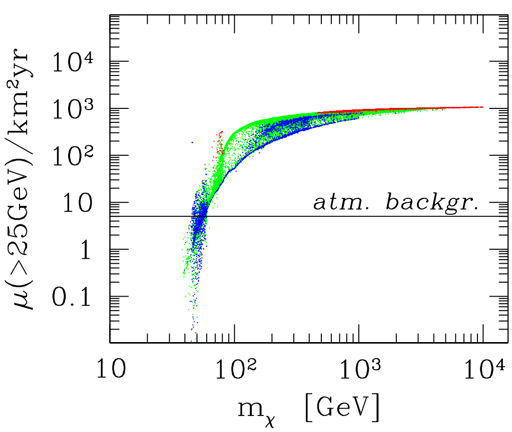

Figure 3. Maximal flux of neutrino-induced muons in a neutrino telescope from neutralino annihilations at the galactic center, after imposing the current constraints on the neutrino emission.

In conclusion, we have shown that if the galactic dark halo is cusped, as favored in recent N-body simulations of galaxy formation, a bright dark matter spike would form around the black hole at the galactic center. A search of a neutrino signal from the spike could either set upper bounds on the density slope of the inner halo or clarify the nature of dark matter.

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